Experimental Investigation of Tubular Heat Exchangers to Enhance Performance Characteristics

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Abstract ***–*** *This study focuses on the various experimental research analyses on performance of tubular heat exchangers the tubular heat exchanger is used throughout various industries because of its inexpensive cost and handiness when it comes to maintenance. In this paper we discus about tubular heat exchanger there are several thermal design factors that are to be taken into account when designing the tubes in the tubular heat exchangers. They are tube diameter, tube length, number of tubes, number of baffles,& baffles inclination etc. The characteristics of flow and heat transfer within the shell are not simple. This paper conducted various experimental analyses to predict the characteristics of difference in temperature and pressure drop, which are the performances of heat exchanger. In this study, the diameter of tube, the number of tubes and the number of baffles are considered as the design factors. Also, factors that affect the performances of heat exchanger were selected through design of experiment procedures. The purpose of this paper is how to improve the performance of tubular heat exchangers.*

Keywords *- Heat Exchanger, Shell and tube, Baffles, Heat transfer.*

1. INTRODUCTION

A tubular heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. It consists of a tube bundle enclosed in a cylindrical casing called a shell. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, so there are many tubes. In this way, waste heat can be put to use. This is a great way to conserve energy. Typically, the ends of each tube are connected to plenums through holes in tube sheets. The tubes may be straight or bent in the shape of a U, called U-tubes. Most tubular heat exchangers are 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, the fluid goes in one end of each tube and out the other. There are two basic types of tubular heat exchangers. The first is the fixed tube sheet unit, in which both tube sheets are fastened to the shell and the tube bundle is not removable. spacing 1.15 inches justified.

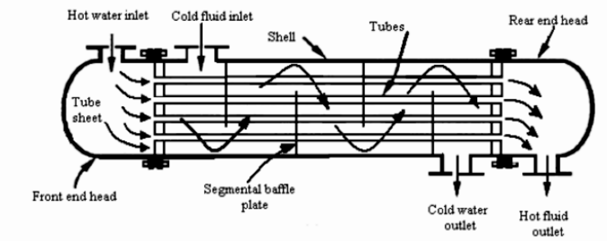


Fig.1 Shell and tube heat exchanger with baffles plate

The second type of shell-and-tube unit has one restrained tube sheet, called the stationary tube sheet, located at the channel end. Differential expansion problems are avoided by use of a freely riding floating tube sheet at the other end or the use of U tubes. This design may be used for single or multiple pass exchangers. The tube bundle is removable from the channel end, for maintenance and mechanical cleaning. There are often baffles directing flow through the shell side so the fluid does not take a short cut through the shell side leaving ineffective low flow volumes. Counter current heat exchangers are most efficient because they allow the highest log mean temperature difference between the hot and cold streams. Many companies however do not use single pass heat exchangers because they can break easily in addition to being more expensive to build. Often multiple heat exchangers can be used to simulate the counter current flow of a single large exchanger. Shell-and-tube exchangers are designed and fabricated according to the standards of the Tubular Exchanger Manufacturers Association (TEMA).

Heat exchangers are used in a wide variety of engineering applications like power generation, waste heat recovery, manufacturing industry, air-conditioning, refrigeration, space applications, petrochemical industries etc. Heat exchanger may be classified according to the following main criteria.

1. Recuperators and Regenerators.
2. Transfer process: Direct contact and Indirect contact.
3. Geometry of construction: tubes, plates and extended surfaces.
4. Heat transfer mechanisms: single phase and two phase.
5. Flow arrangements: parallel, counter and cross flows

Kevin M. Lunsford et al. [1] has analyzed to increase the heat exchanger performance and suggested increasing heat exchanger performance through a logical series of steps. The first step considers if the exchanger is initially operating correctly. The second step considers increasing pressure drop if available in exchangers with single-phase heat transfer. Increased velocity results in higher heat transfer coefficients, which may be sufficient to improve performance. Next, a critical evaluation of the estimated fouling factors should be considered. Heat exchanger performance can be increased with periodic cleaning and less conservative fouling factors. Finally, for certain conditions, it may be feasible to consider enhanced heat transfer through the use of finned tubes, inserts, twisted tubes, or modified baffles.

E.Salehi et al. [2] analyze the shell-side flow of shell-and tube heat exchanger using experimental and theoretical methods. Experimental and numerical results have been compared over a wide range of Reynolds numbers (1,000 t o 1,000,000). The most important results of this research are as follows:

- Comparison of temperature profile of exchanger, with and without baffles, shows that baffles have the vital role in heat transfer rate.
- The results also show that the effect of changing the number of baffles is more important than varying the height of baffles for heat transfer rate inside the shell.
- Increasing Reynolds number in shell-side causes the increase of heat transfer rate. Reynolds number can be increased by adding the number of baffles more easily and with less cost as compared to increasing the inlet velocity of the fluid.

M.A.Mehrabian et al. [3] has the comparison of experimental data with predictions of standard correlations for the overall heat transfer characteristics of a double pipe heat exchanger and concluded that when heat is supplied to the inner tube stream by an immersion heater. The overall heat transfer coefficients are inferred from the measured data. The heat transfer coefficient of the inner tube flow (circular cross section) is calculated using the standard correlations. The heat transfer coefficient of the outer tube flow (annular cross section) is then deduced. Higher heat transfer coefficients are reported in the laminar flow regime in comparison to the predictions of standard correlations for straight and smooth tubes. The Experimental results show that the outer tube side heat transfer coefficients are smaller than the inner side heat transfer coefficients by a factor of almost 1.5 and 3.4 in counter flow and parallel flow arrangements, respectively. The agreement with predictions is very good for the counter flow arrangement, but not very good for the parallel flow arrangement.

Jitendra Kumar Patro [4] discussed about the experimental studies on heat transfer augmentation using TMT rods with and without baffles as inserts for tube side flow of liquids. The different results came are:

- For same baffle spacing 8mm & 10mm inserts with baffles shows greater heat transfer coefficient & friction factor than the value we get for inserts without baffles, because of increased degree of turbulence created.

- On the basis of R1 i.e. Performance evaluation criteria based on constant flow rate, we can say that the 10mm insert with baffle spacing (=10cm) gives the highest R1 range with the maximum value of Heat transfer coefficient around 2.46 times of the value for the smooth tube.

- The effect of 10mm insert (without baffles) and 8mm insert with spacing = 30cm are almost equivalent on both the performance evaluation criteria R1 & fa/fo where fa is friction factor for the tube with inserts and fo is theoretical friction factor for smooth tube.

- With decrease in baffle spacing, heat transfer coefficient increases but at the same time pressure drop also increases

Sunil S. Shinde et al. [5] has studied about the performance Improvement in Single phase Tubular Heat Exchanger using continuous Helical Baffles and investigated that that the performance of tubular heat exchanger can be improved by helical baffles instead of conventional segmental baffles. The use of helical baffles in heat exchanger reduces shell side pressure drop, pumping cost, size, weight, fouling etc. as compare to segmental baffle for new installations. The helix changer type heat exchangers can save capital cost as well as operating and maintenance cost and thus improves the reliability and availability of process plant in a cost effective way. For the helical baffle heat exchangers, the ratios of heat transfer coefficient to pressure drop are higher than those of a conventional segmental heat exchanger. This means that the heat exchangers with helical baffles will have a higher heat transfer coefficient when consuming the same pumping power. It can be concluded that proper baffle inclination angle will provide an optimal performance of heat exchangers.

Abdur Rahim et al. [6] investigate the impacts of various baffle inclination angles on fluid flow and the heat transfer characteristics of a shell-and-tube heat exchanger for three different baffle inclination angles namely 0°, 10° and 20°. The shell side of a small shell-and-tube heat exchanger is modeled with sufficient detail to resolve the flow and temperature fields.

- ➢ For the given geometry the mass flow rate must be below 2 kg/s, if it is increased beyond 2kg/s the pressure drop increases rapidly with little variation in outlet temperature.

- ➢ The pressure drop is decreased by 4 %, for heat exchanger with 10° baffle inclination angle and by 16 %, for heat exchanger with 20° baffle inclination angle.

- ➢ The maximum baffle inclination angle can be 20°, if the angle is beyond 20°, the centre row of tubes are not supported. Hence the baffle cannot be used effectively.

- ➢ Hence it can be concluded tubular heat exchanger with 20° baffle inclination angle results in better performance compared to 10° and 0° inclination angles.

Rajagapal Thundil et al.[7] In the present study, investigate the impacts of various baffle inclination angles on fluid flow and the heat transfer characteristics of a shell-and-tube heat exchanger for three different baffle inclination angles 0°, 10°, and 20°. The simulation results for various tubular heat exchangers, one with segmental baffles perpendicular to fluid flow and two with segmental baffles inclined to the direction of fluid flow are compared for their performance. The shell side design has been investigated numerically by modeling a small shell-and-tube heat exchanger. The following results are concluded:

- ➢ For the given geometry the mass flow rate must be below 2 kg/s, if it is increased beyond 2 kg/s the pressure drop increases rapidly with little variation in outlet temperature.

- ➢ The pressure drop is decreased by 4% for heat exchanger with 10° baffle inclination angle and by 16 % for heat exchanger with 20° baffle inclination angle.

- ➢ The maximum baffle inclination angle can be 20°, if the angle is beyond 20°, the centre row of tubes are not supported. Hence the baffle cannot be used effectively.

- ➢ Tubular heat exchanger with 20° baffle inclination angle results in better performance compared to 10° and 0° inclination angles.

Yong- Gang Li et al. [8] studied the effects of baffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles. The major findings are summarized as follows:

- The average Nusselt number of the tube bundle increases with the increase of baffle inclination angle when α<300, and decreases if the baffle inclination angle increases further.

- The pressure drop decreases with the increase of baffle inclination angle in all the cases considered. The change of the pressure drop is large in the small inclination angle region. However, the effects of baffle inclination angle on pressure drop are small when α>400.

- The heat exchangers with helical baffles will have a higher heat transfer coefficient when consuming the same pumping power. The enhanced performance increases with the increase of baffle inclination angle when α<450, and decreases when α >450.

Su Thet Mon Than, Khin Aung Lin, Mi Sandar Mon:[9] In this paper data is evaluated for heat transfer area and pressure drop and checking whether the assumed design satisfies all requirement or not. The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop. The decreasing pattern of curves of Reynolds Number and heat transfer coefficient shown in figure 5 and figure 6 shows that the Re and h are gradually decreases corresponding as high as tube effective length. Gradual decrease in Reynolds Number means there is significant decrease in pressure drop respectively

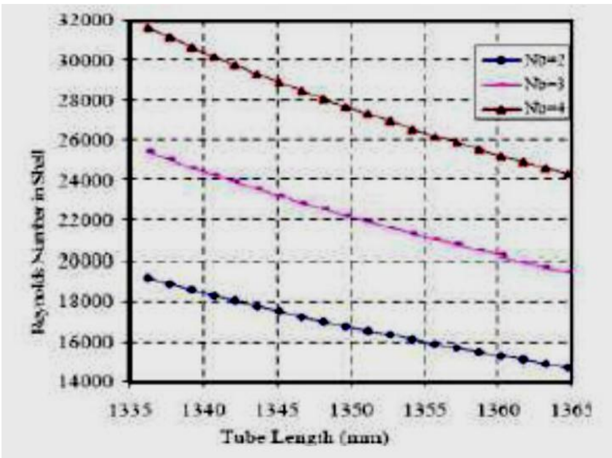


Figure 2: Reynolds Number on Number of Baffles and Length of Tube [9]

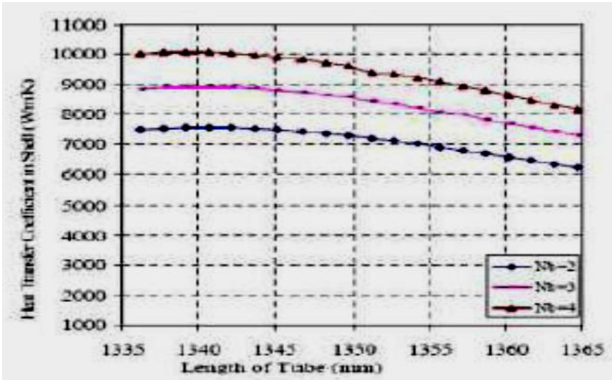


Figure 3: Heat Transfer Coefficient on Number of Baffles and Length of Tube [9]

G.N. Xie, Q.W. Wang , M. Zeng, L.Q. Luo:[10] carried out an experimental system for investigation on performance of shell-and-tube heat exchangers, and limited experimental data is obtained. The ANN is applied to predict temperature differences and heat transfer rate for heat exchangers. BP algorithm is used to train and test the network. It is shown that the predicted results are close to experimental data by ANN approach. Comparison with correlation for prediction heat transfer rate shows ANN is superior to correlation, indicating that ANN technique is a suitable tool for use in the prediction of heat transfer rates than empirical correlations. It is recommended that ANNs can be applied to simulate thermal systems, especially for engineers to model the complicated heat exchangers in engineering applications.

Usman Ur Rehman [11] had investigated an un-baffled shell-and-tube heat exchanger design with respect to heat transfer coefficient and pressure drop by numerically modeling. The heat exchanger contained 19 tubes inside a 5.85m long and 108mm diameter shell. The flow and temperature fields are resolved using a commercial CFD package and it is performed for a single shell and tube bundle and is compared with the experimental results. Standard k- ε model is used first to get the flow distribution but it is not good for predicting the boundary layer separation and impinging flows. For this reason, Realizable k – ε model is used with standard and then Non-equilibrium wall functions. The non-equilibrium wall functions with Realizable k- ε model give better results than standard k- ε model. The pressure drop heat transfer still are being over predicted by almost 25%, which is probably due to y+ values limitations at tube walls .Thus in order to avoid this and to include the low Reynolds modification SST k-ω model is also used. Because it uses both k - ε and k- ω model in the region of high and low Reynolds number respectively. SST k-ω model has provided the reliable results with the y+ limitations. Thus the modeling can also be improved by using Reynolds Stress Models, but with higher computational costs and the enhanced wall functions are not used. The heat transfer is found to be poor because the most of the shell side fluid by-passes the tube bundle without interaction. Thus the design can be modified to achieve the better heat transfer in two ways. Either, the shell diameter is reduced or tube spacing can be increased .Thus the design can further be improved by creating cross-flow regions in such a way that flow doesn't remain parallel to the tubes. It will allow the outer shell fluid to mix with the inner shell fluid and will automatically increase the heat transfer.

Apu Roy, D.H.Das [12] the present work has been carried out with a view to predicting the performance of a shell and finned tube heat exchanger in the light of waste heat recovery application. Energy available in the exit stream of many energy conversion devices such as I.C engine gas turbine etc goes as waste, if not utilized properly. The performance of the heat exchanger has been evaluated by using the CFD package fluent 6.3.16 and the available values are compared with experimental values. By considering different heat transfer fluids the performance of the above heat exchanger can also be predict. The performance parameters of heat exchanger such as effectiveness, overall heat transfer coefficient, energy extraction rate etc, have been taken in this work.

COMPUTATIONAL FLUID DYNAMICS

CFD is useful for studying fluid flow, heat transfer; chemical reactions etc by solving mathematical equations with the help of numerical analysis.CFD resolve the entire system in small cells and apply governing equations on these discrete elements to find numerical solutions regarding pressure distribution, temperature gradients. [13] This software can also build a virtual prototype of the system or device before can be apply to real-world physics to the model, and the software will provide with images and data, which predict the performance of that design. More recently the methods have been applied to the design of internal combustion engine, combustion chambers of gas turbine and furnaces, also fluid flows and heat transfer in heat exchanger. The development in the CFD field provides a capability comparable to other Computer Aided Engineering (CAE) tools such as stress analysis codes. [14] Basic Approach to using CFD a) Pre-processor: Establishing the model

- Identify the process or equipment to be evaluated.
- Represent the geometry of interest using CAD tools.
- Use the CAD representation to create a volume flow domain around the equipment containing the critical flow phenomena.
- Create a computational mesh in the flow domain.

b) Solver:

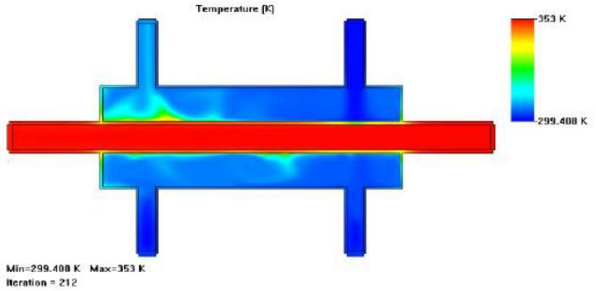
- Identify and apply conditions at the domain boundary.
- Solve the governing equations on the computational mesh using analysis software.
- Post processor: Interpreting the results
- Post-process the completed solutions to highlight findings.
- Interpret the prediction to determine design iterations or possible solutions, if needed

CONCLUSION

In this paper, numerical simulation of tubular heat exchanger is conducted to study the effect of baffle and its different orientations. Simulations were conducted to calculate the heat transfer coefficient at different fluid velocities .It is concluded that use of baffle has significant impact on tubular heat exchanger. The major findings are summarized as follow:

- Study of heat transfer of the heat exchanger at different flow rates.
- The output results coming out from heat exchanger having baffles situated at outer pipe are more efficient from heat exchanger without baffles.

Fig.4 Temperature contours for hot water through inner pipe for without baffle



- The results of heat transfer coefficient coming out by use of 30^0 baffles are more efficient than 0^0 baffles. As the angle of inclination increases, the heat transfer rate of heat exchanger also increases.

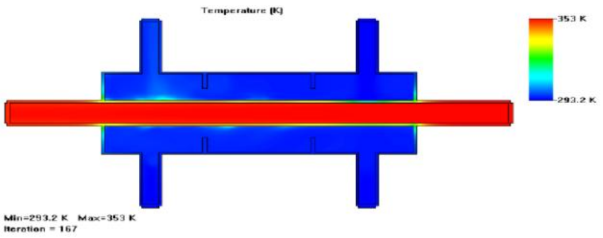
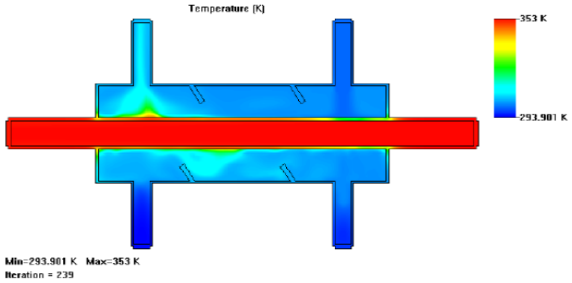


Fig.4Temperature contours for hot water through inner pipe for (a)with baffle at 0^0 (b)with baffle at 30^0



- As the Reynolds number increases in a heat exchanger, the heat transfer coefficient will also increase

- From the Numerical & experimental results it is confirmed that the performance of tubular heat exchanger can be improved by helical baffles instead of conventional segmental baffles.

- Use of helical baffles in heat exchanger reduces shell side pressure drop, pumping cost, size, weight, fouling etc. as compare to segmental baffle for new installations. The helix changer type heat exchangers can save capital cost as well as operating and maintenance cost and thus improves the reliability and availability of process plant in a cost effective way.

- For the helical baffle heat exchangers, the ratios of heat transfer coefficient to pressure drop are higher than those of a conventional segmental heat exchanger. This means that the heat exchangers with helical baffles will have a higher heat transfer coefficient when consuming the same pumping power.

- It can be concluded that proper baffle inclination angle will provide an optimal performance of heat exchangers

SCOPE FOR FUTURE WORK

With the CFD analysis of single pass tubular heat exchanger with and without baffles, test runs will be made for at least five different flow rates (Reynolds Numbers). The heat exchanger performance will be evaluated for at least five different inlet temperatures for parallel and counter flows. The three different baffle orientations (i.e 0**0**,30**0** and 60**0**) will be studied for the corresponding flow rates, inlet temperatures, parallel and counter flows leading to total 150 test runs. The analysis of heat transfer rate in heat exchanger is also concluded by varying the baffle spacing. The experimental results are compared with the CFD results and correlations will be developed with respect to these conditions for the Nusselt number and other flow parameters.

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